



## Bagasse Fiber Composites-A Review

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### Abstract

A composite material is made by combining two or more materials to give a unique combination of properties, one of which is made up of stiff, long fibres and the other, a binder or 'matrix' which holds the fibres in place. The fibres are strong and stiff relative to the matrix and are generally orthotropic. More recently natural fibers have been employed in combination with plastics. The abundant availability of natural fibre in India such as Jute, Coir, Sisal, Pineapple, Ramie, Bamboo, Banana etc. gives attention on the development of natural fibre composites primarily to explore value-added application avenues. Such natural fibre composites are well suited as wood substitutes in the housing and construction sector. Reinforcement with natural fibre in composites has recently gained attention due to low cost, low density, acceptable specific properties, ease of separation, enhanced energy recovery, CO<sub>2</sub> neutrality, biodegradability and recyclable nature. Thousands of tons of different crops are produced but most of their wastes do not have any useful utilization. Agricultural wastes include wheat husk, rice husk and their straw, hemp fibre and shells of various dry fruits. These agricultural wastes can be used to prepare fibre reinforced polymer composites for commercial use. This review discusses the use of bagasse fibre and its current status of research. Many references to the latest work on properties, processing and application have been cited in this review

**Keywords:** Natural fibres, Bagasse fibres, Polymer resin, sugar cane

### 1. Introduction

#### 1.1 Need of Composites:

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and numbers of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years.

The introduction of newer polymer resin matrix materials and high performance reinforcement fibres of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume. The increased has resulted in an expected reduction in costs. High performance FRP can now be found in such diverse applications as composite armoring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets of pre-

existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity.

Whilst the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working, lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience & skills the designer in tapping the optimum potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials.

### *1.2 Definition of Composite*

According to Jartz [1] "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form".

The weakness of this definition resided in the fact that it allows one to classify among the composites any mixture of materials without indicating either its specificity or the laws which should give it which distinguishes it from other very banal, meaningless mixtures.

Kelly [2] very clearly stated that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength to resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them.

Beghezan [3] defined as "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings", in order to obtain improved materials.

Van Suchetclan [4] explained composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

### *1.3 Properties of Composites*

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the 'reinforcement' or 'reinforcing material', whereas the continuous phase is termed as the 'matrix'.

Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties.

Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures. Composites are now extensively being used for rehabilitation strengthening constituent materials; the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties.

## **1.4 Elements of Composite Materials:**

A composite material is one, which is made of at least two elements working together to give material properties that are different to the properties of those elements on their own. Most composites consist of a bulk material ('matrix') and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

### *1.4.1 Importance of matrix in a composite:*

Many materials when they are in a fibrous form exhibit very good strength property but to achieve these properties the fibres should be bonded by a suitable matrix. The matrix isolates the fibres from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibres in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibres and evenly distributive stress concentration.

**1.4.2 Materials used as matrix in composites:**

**1.4.2.1 Bulk Phases**

Bulk phases consist of following matrix systems:

**1.4.2.1.1 Metal Matrix**

Metal matrix composites possess some attractive properties, when compared with organic matrices. These include

- (i) Good strength at higher temperatures,
- (ii) Higher transverse strength,
- (iii) Excellent electrical conductivity,
- (iv) superior thermal conductivity,
- (v) Higher erosion resistance etc.

However, the major disadvantage of metal matrix composites is their higher densities and consequently lower specific mechanical properties compared to polymer matrix composites. Another notable difficulty is the high-energy requirement for fabrication of such composites.

**1.4.2.1.2 Polymer Matrix**

A very large number of polymeric materials, both thermosetting and thermoplastic, are used as matrix materials for the composites.

Some of the major advantages and limitations of resin matrix are shown in Table 1.

**Table 1:** Advantages and Limitations of resin matrix

advantages	limitations
1. Low Densities	1. Low Transverse Strength.
2. Good Corrosion Resistance	2. Low Operational Temperature Limits
3. Low Thermal Conductivities	
4. Low Electrical Conductivities	
5. Translucence	
6. Aesthetic Color Effects	

In general, the polymer matrices are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. The resin must have mechanical strength commensurate with that of the reinforcement. It must be easy to use in the fabrication process selected and also stand up to the service conditions. Apart from these properties, the resin matrix must be capable of wetting and penetrating into the bundles of fibres which provide the reinforcement, replacing the dead air spaces therein and offering those physical characteristics capable of enhancing the performance of fibres.

**1.4.2.1.3 Ceramic Matrix**

Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non-metal. Ceramic materials may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics, but many different ceramic materials are now used in domestic, industrial and building products. Ceramic materials tend to be strong, stiff, brittle, chemically inert and non-conductors of heat and electricity, but their properties vary widely. For example, porcelain is widely used to make electrical insulators, but some ceramic compounds are superconductors.

Ceramic fibres, such as alumina and SiC (Silicon Carbide) are advantageous in very high temperature applications and also where environment attack is an issue. Since ceramics have poor properties in tension and shear, most applications as reinforcement are in the particulate form (e.g. zinc and calcium phosphate). Ceramic Matrix Composites (CMCs) used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

#### *1.4.2.2 Reinforcement*

The purpose of the reinforcement in a composite material is to increase the mechanical properties of the neat resin system. All of the different fibres used in composites have different properties and so affect the properties of the composite in different ways. For most of the applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible.

#### *1.4.2.3 Interface*

It has characteristics that are not depicted by any of the component in isolation. The interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical, chemical etc. The matrix material must “wet” the fiber. Coupling agents are frequently used to improve wet ability. Well “wetted” fibres increase the interface surfaces area. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibres via the interface. This means that the interface must be large and exhibit strong adhesion between fibres and matrix. Failure at the interface (called debonding) may or may not be desirable.

## **2. Classification**

Composite materials can be classified in different ways [5] A typical classification is presented in FIG1.1. The two broad classes of composites are (1) Particulate composites and (2) Fibrous composites.

### *2.1 Particulate Composites*

As the name itself indicates, the reinforcement is of particle nature (platelets are also included in this class). It may be spherical, cubic, tetragonal, a platelet, or of other regular or irregular shape, but it is approximately equiaxed. In general, particles are not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particle fillers are widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage.

### *2.2 Fibrous composites*

A fibre is characterized by its length being much greater compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibres are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices.

Man-made filaments or fibres of non-polymeric materials exhibit much higher strength along their length since large flaws, which may be present in the bulk material, are minimized because of the small cross-sectional dimensions of the fibre. In the case of polymeric materials, orientation of the molecular structure is responsible for high strength and stiffness.

Fibres, because of their small cross-sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. The matrix serves to bind the fibres together, transfer loads to the fibres and protect them against environmental attack and damage due to handling. In discontinuous fibre reinforced composites, the load transfer function of the matrix is more critical than in continuous fibre composite.

### *2.3 Natural Fiber Composites*

Natural fiber composites are made of Cotton, Flax, Jute, Sisal, Hemp and non-conventional fiber such as Coir & different EFBs (empty fruit bunches) and Wood fibers. Wood fiber thermoplastic composites are attractive, insect- and rot-resistant, paintable and can be made to have the look of wood. In addition, they are stiffer, cheaper than plastic products, with more life-cycle coseo, Vegetable fiber thermoplastic composites are attractive to the automotive industry because of their low density and ecological advantages over conventional composites Natural fibres are lingo cellulosic in nature. These composites are gaining importance due to their non-carcinogenic and bio-degradable nature [6-9]. The natural fiber composites can be very cost effective material especially for building and construction industry (panels, false ceilings, partition boards etc.) packaging, automobile and railway coach interiors and storage devices. This also can be a potential candidate

in making of composites, especially for partial replacement of high cost glass fibers for low load bearing applications. However in many instances residues from traditional crops such as rice husk or sugarcane bagasse or from the usual processing operations of timber industries do not meet the requisites of being long fibers. This biomass left over are abundant and their use as a particulate reinforcement in resin matrix composite is strongly considered as a future possibility.

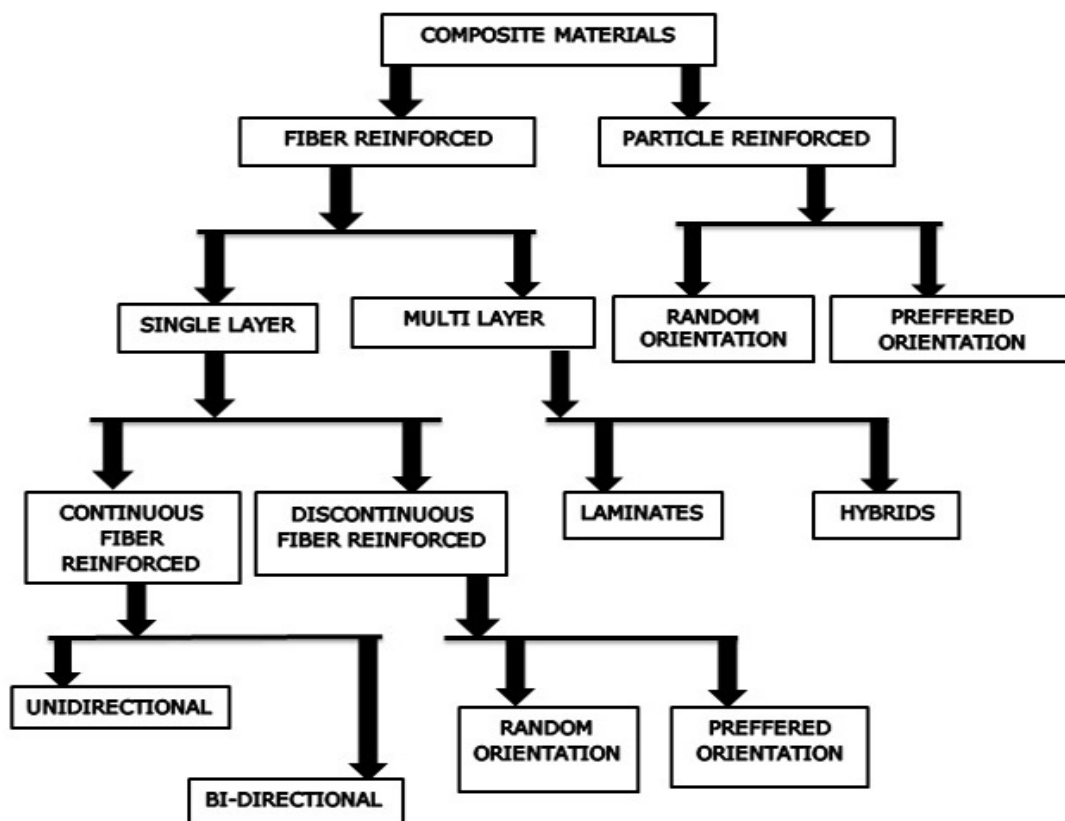


Fig 1.1 Classifications of Composite Materials

Large varieties of sugar cane grow abundantly in many parts of India. Cane is crushed in a series of mills each consisting of at least three heavy rollers. Due to the crushing, the cane stalk will break in small pieces and subsequent milling will squeeze the juice out. The juice is collected and processed for production of sugar. The resulting crushed and squeezed cane stalk, named bagasse, is considered to be a by-product of the milling process [10]. Bagasse is essentially a waste product that causes mills to incur additional disposal costs. Bagasse is a fibrous residue that remains after crushing the stalks and contains short fibers (Fig. 1.2). It consists of water, fibers and small amounts of soluble solids. Percent contribution of each of these components varies according to the variety, maturity, method of harvesting and the efficiency of the crushing plant. Table 2 shows a typical bagasse composition.

**Table 2:** Average Bagasse Compositions

items	percentage (%)
1. Moisture	49.0
2. Soluble solids	02.3
3. Fibre	48.7

Bagasse is mainly used as a burning raw material in the sugar cane mill furnaces. The low caloric power of bagasse makes this a low efficiency process. Also, the sugar cane mill management encounters problems

regarding regulations of “clean air” from the Environmental Protection Agency, due to the quality of the smoke released in the atmosphere. Presently 85% of bagasse production is burnt. Even so, there is an excess of bagasse. Usually this excess is deposited on empty fields altering the landscape. Approximately 9% of bagasse is used in alcohol (ethanol) production. Ethanol is not just a good replacement for the fossil fuels, but it is also an environmentally friendly fuel. Apart from this, ethanol is a very versatile chemical raw material from which a variety of chemicals can be produced [11]. But again, due to the low level of sucrose left in bagasse, the efficiency of the ethanol production is quite low.

With increasing emphasis on fuel efficiency, natural fibers such as bagasse based composites enjoying wider applications in automobiles and railway coaches & buses for public transport system. There exist an excellent opportunity in fabricating bagasse based composites towards a wide array of applications in building and construction such boards and blocks as reconstituted wood, flooring tiles etc. Value added novel applications of natural fibers and bagasse based composites would not go in a long way in improving the quality of life of people engaged in bagasse cultivation, but would also ensure international market for cheaper substitution.

Natural fibers have the advantages of low density, low cost and biodegradability. However, the main disadvantages of natural fibers and matrix and the relative high moisture sorption. Therefore, chemical treatments are considered in modifying the fiber surface properties.

A better understanding of the chemical composition and surface adhesive bonding of natural fiber is necessary for is necessary for developing natural fiber-reinforced composites. The components of natural fibers include cellulose, hemicellulose, lignin, pectin, waxes and water soluble substances. The composition of selected natural fibers is shown in Table 1.3 [12, 13]. The composition may differ with the growing condition and test methods even for the same kind of fiber. Cellulose is a semi crystalline polysaccharide made up of D-glucopyranose units linked together by  $\beta$ -(1-4)-glucosidic bonds [13] and the large amount of hydroxyl group in cellulose gives natural fiber hydrophilic properties when used to reinforce hydrophobic matrix; the result is a very poor interface and poor resistance to moisture absorption [14]. Hemicellulose is strongly bound to cellulose fibrils presumably by hydrogen bonds. Hemicellulosic polymers are branched, fully amorphous and have a significantly lower molecular weight than cellulose. Because of its open structure containing many hydroxyl and acetyl groups, hemicellulose is partly soluble in water and hygroscopic [15]. Lignins are amorphous, highly complex, mainly aromatic, polymers of phenyl propane units [13] but have the least water sorption of the natural fiber components [15]. Because of the low interfacial properties between fiber and polymer matrix often reduce their potential as reinforcing agents due to the hydrophilic nature of natural fibers, chemical modifications are considered to optimize the interface of fibers. Chemicals may activate hydroxyl groups or introduce new moieties that can effectively interlock with the matrix. The development of a definitive theory for the mechanism of bonding by chemicals in composites is a complex problem. Generally, chemical coupling agents are molecules possessing two functions. The first function is to react with hydroxyl group of cellulose and the second is to react with functional groups of the matrix.



**Fig 1.2 : BAGASSE**

Visualizing the increased rate of utilization of natural fibers the present work has been undertaken to develop a polymer matrix composite (epoxy resin) using bagasse fiber and fly ash as reinforcement and to study its mechanical properties and environmental performance. The composites are to be prepared with different fraction of bagasse fibers.

#### **4. Literature Survey**

Researchers have begun to focus attention on natural fiber composites (i.e., bagasse fiber), which are composed of natural or synthetic resins, reinforced with natural fibers. Natural fibers exhibit many advantageous properties, they are a low-density material yielding relatively lightweight composites with high specific properties. These fibers also have significant cost advantages and ease of processing along with being a highly renewable resource, in turn reducing the dependency on foreign and domestic petroleum oil.

Usmani M.Arthur et al (1981) [16] described the evaluation of five water soluble phenolic resins as binders, at 5 percent concentration, for oriented and random bagasse-reinforced composite materials. Determined the amount of resin retained during processing when these phenolics are precipitated from water slurry onto the bagasse fibers. The physical properties of random oriented cured composites (wet and dry) were determined. Random fiber composites were also prepared by a "moist" process (in which no resin is lost) and compared. A specific resin was selected as best based on retained mechanical properties and minimal phenolic processing losses.

D. Maldas et al (1990) [17] studied the effect of thermoplastics (e.g. polyvinyl chloride and polystyrene), as well as a coupling agent — poly (methylene (polyphenylisocyanate)) (PMPPIC) — and bagasse lignin, on the mechanical properties of particle boards of sugarcane bagasse. The mechanical properties of bagasse particle boards were compared to those of hardwood aspen fiber particle boards, delignified bagasse particle boards, as well as those of composites made from bagasse, polymers and coupling agents. Particle boards of bagasse comprising both thermoplastics and a coupling agent offer superior properties compared to those made of only thermoplastic or a coupling agent. The extent of improvement in the mechanical properties of particle boards depended on the concentration of polymers and the coupling agent; nature of the fiber, polymer and coupling agent; composition of PMPPIC and bagasse; as well as lignin content of the bagasse. Moreover, the mechanical properties and dimensional stability of coupling agent-treated particle boards are superior to non-treated ones.

Monteiro S.N. et al (1998) studied [18] the possible uses of bagasse waste as reinforcement in polyester matrix composites. Preliminary results have attested this possibility. Composites with homogeneous microstructures could be fabricated and the levels of their mechanical properties enable them to have practical applications similar to the ones normally associated with wooden agglomerates. Future developments are expected to increase the performance and competitiveness of these composites as compared to those of other materials in the same structural class.

Vazquez A. et al (1999) reported [19] processing and properties of bagasse fiber-polypropylene composites. Four different chemical treatments of the vegetal fibers were performed in order to improve interface adhesion with the thermoplastic matrix: namely isocyanate, acrylic acid, mercerization and washing with alkaline solution were applied. The effects of the treatment reactions on the chemical structure of the fibers were analysed by infrared spectroscopy. Optical photomicrographs indicate that a highly fibrillated surface is achieved when fibers are mercerized. The effects of the fiber chemical treatment on the tensile properties of the molded composite, produced by different processing routes, were also analysed. It was observed that the tensile strength and the elongation at break of the polypropylene matrix composite decrease with the incorporation of bagasse fibers without treatment. However, isocyanate and mercerization treatments enhance the tensile properties of the composite. Moreover, creep measurements were also carried out on the various composites studied. The best results were obtained on materials with treated fibers. The highest creep activation energy was obtained on the composite with the mercerized fiber.

Hassan M.L et al (2000) investigated [20] the conversion of bagasse into a thermo formable material through esterification of the fiber matrix. For this purpose, bagasse was esterified in the absence of solvent using succinic anhydride (SA). The reaction parameters of temperature reaction, time and amount of succinic anhydride added were studied. Ester content, Fourier transform infrared (FTIR), thermo gravimetric analysis (TGA), differential scanning calorimetry (DSC) and dynamic mechanical thermal analysis (DMTA) were used to characterize the chemical and thermal properties of the esterified fibers. The results showed that on reacting

bagasse with SA in the absence of solvent, ester content up to about 48% could be obtained. Diester formation increased with increasing reaction time and temperature at high levels of ester content. Ester content determination of the esterified fibers and their corresponding holocelluloses showed that the reaction took place in the lignin and holocellulose components of bagasse. The IR results showed that the crystallinity index of different esterified bagasse samples did not decrease as a result of increasing the ester content. DSC and TGA results showed that esterified-bagasse fibers were less thermally stable than the untreated fibers. DMTA results showed that esterification of the fibers resulted in a decrease in the  $\tan \delta$  peak temperature of the esterified fibers compared to the untreated fiber.

Hassan M.L et al (2000) investigated [21] the conversion of bagasse into a thermomoldable material through esterification of the fiber matrix. For this purpose, bagasse fiber was esterified in the absence of solvent using succinic anhydride. The dimensional stability and mechanical properties of composites prepared from the esterified fibers were studied. Dimensional stability was found to be dependent on the total ester and monoester/diester content of esterified fibers and increased with increasing total ester and monoester content of the fibers. The mechanical properties (bending strength, tensile strength and hardness) were enhanced with increasing monoester contents. Scanning electron microscopy was used to prove the occurrence of thermo plasticization of the esterified fibers

Paiva J.M.F. et al (2002) confirmed [22] that Lignin, extracted from sugarcane bagasse by the organosolv process, used as a partial substitute of phenol (40 w/w) in resole phenolic matrices. Short sugarcane fibers were used as reinforcement in these polymeric matrices to obtain fiber-reinforced composites. Thermoset polymers (phenolic and lignophenolic) and related composites were obtained by compression molding and characterized by mechanical tests such as impact, Differential Mechanical Thermo analysis (DMTA) and hardness tests. The impact test showed an improvement in the impact strength when sugarcane bagasse was used. The inner part of the fractured samples was analysed by scanning electron microscopy (SEM) and the results indicated adhesion between fibers and matrix, because the fibers are not set free, suggesting they suffered a break during the impact test. The modification of fiber surface (mercerization and esterification) did not lead to an improvement in impact strength. The results as a whole showed that it is feasible to replace part of phenol by lignin in phenolic matrices without loss of properties.

Bilba K et al (2003) prepared [23] various bagasse fibre/cement composites, the fibres having a random distribution in the composites. The influence of different parameters on the setting of the composite material has been studied: (1) botanical components of the fibre, (2) thermal or chemical treatment of the fibre, (3) bagasse fibre content and (4) added water percentage. This study shows a retarding effect of lignin on the setting of the composite, for small amount of heat-treated bagasse (200 °C) the behaviour of the composite is closely the same as the classical cement or cellulose/cement composite.

Thwe MM et al (2003) studied [24] the effects of environmental aging and accelerated aging on tensile and flexural behavior of bamboo fiber reinforced polypropylene composite (BFRP) and bamboo-glass fiber reinforced polypropylene hybrid composite (BGRP), all with a 30% (by mass) fiber content, by exposing the samples in water at 25°C for up to 1600 h and at 75°C for up to 600 h. Reduction in tensile strength for BFRP and BGRP was 12.2% and 7.5%, respectively, after aging at 25°C for about 1200 h. Tensile and flexural strength of BFRP and BGRP were reduced by 32%, 11.7% and 27%, 7.5% respectively, after aging at 75°C for 600 h. While the strengths of the bamboo fiber reinforced composites reduce with sorption time and temperature, the environmental degradation process can be delayed by adding a small amount of glass fiber. Moisture sorption and strength reduction are further suppressed by using maleic anhydride polypropylene (MAPP) as a coupling agent in both types of composite system.

Songklanakarinn et al (2004) investigated [25] that Bagasse fly ash, a waste from the sugar industry can be used as a replacement for the current expensive methods of removing reactive dyes (Remazol Black B; RBB, Remazol Brilliant Blue R; RBBR and Remazol Brilliant Red F3B; RBRF3B) from aqueous solutions. Bagasse fly ash was collected from a local sugar factory in Saraburi province, Thailand. It was oven dried at 110°C overnight and sieved to the desired particle size of 150  $\mu\text{m}$  or smaller. The 50 mL plastic conical tubes containing solution and bagasse fly ash were shaken at room temperature ( $27 \pm 2^\circ\text{C}$ ). The pH values of solutions were adjusted by addition of  $\text{HNO}_3$  and  $\text{NaOH}$ . The batch study indicated that initial pH of aqueous solutions did not affect dye removal. While the removal efficiency decreased with increasing initial concentration, it increased with increasing adsorbent concentration. The best adsorptions were obtained under condition of 50 mg/L concentration, original pH solution of about 5 and 240, 300 and 240 minutes contact time for RBB, RBBR and RBRF3B, respectively. Most adsorption experiments showed in the range of about



50% to 98% removal; that is, the efficiencies of RBB, RBBR and RBRF3B adsorption were found to be between 58.48-98.03%, 46.15-93.47% and 46.30- 94.60%, respectively. For the linear and nonlinear forms of the Langmuir and Freundlich models, the results indicated that the Langmuir adsorption isotherm fitted the data better than the Freundlich adsorption isotherm. Adsorption of these dyes onto bagasse fly ash was favorable sorption. Therefore, bagasse fly ash, the low-cost agricultural waste in Thailand, is suitable for use as adsorbent for RBB, RBBR and RBRF3B under this investigation.

Sausa de M.V et al (2004) evaluated [26] the effect of three processing parameters on the flexural mechanical behavior of chopped bagasse–polyester composites. The parameters evaluated were: the size of the chopped material, the pre-treatment derived from the previous processing of the bagasse material on mills for extraction of sugar and alcohol or liquor and the molding pressure. The results obtained showed that composites fabricated with bagasse with size under mesh #20 sieve and pre-processed for sugar and alcohol extraction showed the best mechanical performance. This behavior was associated, respectively, with the increase of the surface area and with an almost complete cleaning of the bagasse surface. The molding pressure affects the mechanical behavior only after a threshold value is attained. Its effect was related to the promotion of a closer contact between bagasse and the resin matrix and the reduction of entrapped voids. The results obtained enable the selection of the best combination of bagasse origin, size and molding pressure

Shinichi Shibata et al (2005) by experiment [27] investigated flexural modulus of the press-molding composites made from bagasse fiber and biodegradable resin and numerical prediction with Cox's model that incorporates the compression ratio of the bagasse fiber in the cross section. The effect of the volume fraction of bagasse fiber and its length on the flexural modulus was examined. Up to 65% volume fraction in the experiment, the flexural modulus increased with increase of the fraction of the bagasse fiber. The numerical prediction was in good agreement with the experimental result. Above 65% volume fraction, however, the flexural modulus decreased in the experiment, while the prediction increased. It seemed that the biodegradable resin was insufficient to cover all the surface of bagasse fiber in the composite. Moreover, the decrease of the flexural modulus was found below 3 mm at the fiber length in the experimental and the same trend was shown in the numerical prediction.

Shibata S. et al (2006) prepared [28] biodegradable composites reinforced with bagasse fibre before and after alkali treatments and mechanical properties were investigated. Mechanical properties of the composites made from alkali treated fibres were superior to the untreated fibres. Composites of 1% NaOH solution treated fibres showed maximum improvement. Approximately 13% improvement in tensile strength, 14% in flexural strength and 30% in impact strength had been found, respectively. After alkali treatment, increase in strength and aspect ratio of the fibre contributed to the enhancement in the mechanical properties of the composites. SEM observations on the fracture surface of composites showed that the surface modification of the fibre occurred and improved fibre–matrix adhesion.

S.M. Luz et al (2007) performed [29] the compression and injection molding processes in order to evaluate the better mixer method for fiber (sugarcane bagasse, bagasse cellulose and benzylated bagasse) and matrix (polypropylene). The samples (composites and polypropylene plates) were cut and submitted to mechanical tests in order to measure flexural and tensile properties. The morphological and microstructural analyses of fracture surface and specimens from composites can be easily evaluated by microscopic techniques. The fracture surface was evaluated by SEM and selected specimens from composites were analysed by reflected light in OM. The better tested method for composites obtainment was the injection molding under vacuum process, by which composites were obtained with homogeneous distribution of fibers and without blisters. The mechanical property shows that the composites did not have good adhesion between fiber and matrix; on the other hand, the fiber insertion improved the flexural modulus and the material rigidity.

Zheng Yu-Tao et al (2007) studied [30] the surface treatments of bagasse fibre (BF) with benzoic acid as a surface/interface modifier and the mechanical properties of BF-polyvinyl chloride (PVC) composite. A typical process for the preparation of the composite was as follows: A mixture of PVC, BF, benzoic acid and other processing additives were dry-blended in a two-roll mill followed by compression molding. The experimental results indicated that the ratio of PVC/BF, the content of benzoic acid and processing temperature had a significant effect on the mechanical properties of the composite, which was examined by the orthogonal optimal method. The interface modifier improved significantly on the tensile strength and little on the impact strength of the composite, for example, the tensile strength changed between 42 and 52 MPa comparing to the tensile strength of untreated BF/PVC composite (38 MPa) and the impact strength changed between 8.3 and

9.2 kJ/m<sup>2</sup> comparing to the impact strength of untreated BF/PVC composite (7.5 kJ/m<sup>2</sup>) when the content of benzoic acid changed between 3 and 10%.

Tayeb et al (2008) studied [31] abrasive wear behaviour of polymer reinforced with natural fibre. Specifically, untreated sugarcane fibre (SCF) was used in two forms to reinforce polyester (SCRCP). Chopped SCFs with different lengths (1, 5, 10 mm) randomly dispersed (C-SCRCP) and continuously unidirectional fibres (U-SCRCP) with two different orientations were prepared using hand-lay-up and closed mould techniques. Despite the good adhesion between fibre and matrix, results of mechanical tests showed poor tensile strength of SCRCP composite. This was attributed to the weak site inside the fibre itself which could not bear the stress transfer from matrix via the fibre. Experimental results of abrasive wear tests revealed that wear of SCRCP composite was sensitive to variations of load, fibre length and fibre orientation and less sensitive to sliding velocity. In C-SCRCP composite, the lowest wear resistance was observed for composite with 1 mm fibre length as the fibres had no support and removed easily with minimum resistance to the action of abrasive particles followed by 10 and 5 mm fibre length. Meanwhile, C-SCRCP composite with 5 mm fibre length offered the highest resistance to material removal compared to the other fibre length used. In U-SCRCP composite, the anti-parallel-orientation (APO) exhibited better wear performance compared to the parallel-orientation (PO) one. The predominant wear mechanisms in the case of C-SCRCP composite were plastic deformation, micro-cutting, pitting in the matrix and fibre removal. In the case of U-SCRCP composite in (PO) wear mechanisms were micro-cutting, ploughing, fragmentation of wear debris in the matrix and excessive deterioration of fibre surface followed by delamination, while in (APO) the wear mechanisms were micro-cutting in the resin matrix and tearing the fibre transversely at their ends.

Acharya S.K et al (2008) found [32] that the sugar cane residue bagasse is an underutilized renewable agricultural material. Bagasse is generally grey-yellow to pale green in color. It is bulky and quite non uniform in particle size. As it is produced at the sugar mills, bagasse is used as fuel in the power plant. However, wherever there is large scale production of sugarcane, there will be excess bagasse which must be disposed of by other methods such as burning, dumping, land burial, etc. Thus, an economic use of the excess bagasse could both increase the profits of the sugar mill and solve an environmental problem. The attempt to upgrade the value of this agricultural residue has been made by bonding with resin to produce composites for suitable applications.

C.P. da Silva et al (2009) used [33] natural fibers both pre-treated and modified residues from sugarcane bagasse. Polymer of high density polyethylene (HDPE) was employed as matrix in to composites, which were produced by mixing high density polyethylene with cellulose (10%) and Cell/ZrO<sub>2</sub>·nH<sub>2</sub>O (10%), using an extruder and hydraulic press. Tensile tests showed that the Cell/ZrO<sub>2</sub>·nH<sub>2</sub>O (10%)/HDPE composites present better tensile strength than cellulose (10%)/HDPE composites. Cellulose agglomerations were responsible for poor adhesion between fiber and matrix in cellulose (10%)/HDPE composites. HDPE/natural fibers composites showed also lower tensile strength in comparison to the polymer. The increase in Young's modulus is associated to fibers reinforcement. SEM analysis showed that the cellulose fibers insertion in the matrix caused an increase of defects, which were reduced when modified cellulose fibers were used.

V. S. Aigbodion et al (2010) characterized [34] the chemical and physical nature of bagasse ash in order to evaluate the possibility of their use in the industry. X-ray diffractometry, determination of composition and presence of crystalline material, scanning electron microscopy/EDAX examination of morphology of particles, as well as physical properties and refractoriness of, bagasse ash has been studied.

V. S. Aigbodion et al (2010) developed [35] the thermal ageing behaviour model of Al-Cu-Mg/Bagasse ash particulate composites with 2-10wt% bagasse ash particles produced by double stir-casting method in terms of weight fraction of bagasse ash, ageing temperature and time. Hardness values measurement was used in determining the ageing behaviour, after solution and age-hardened heat-treatment. The experimental results demonstrate that the bagasse ash was the major parameter in the ageing behaviour, followed by ageing temperature. The hardness values decreased as the ageing time increases. Moreover, the optimal combination of the testing parameters could be predicted. The predicted hardness values were found to lie close to that of the experimentally observed ones. The developed mathematical model can be employed for optimization of the process parameters of the ageing behaviour of Al-Cu-Mg/Bagasse ash particulate composites with respect to hardness values.

S. K. Acharya et al (2010) carried out [36] experiments to study the effects of impingement angle and particle velocity on the solid particle erosion behavior of Bagasse Fiber Reinforced Polymer Composites (BFRPCs). The erosive wear is evaluated at different impingement angles from 30° to 90° at four different velocities of

48, 70, 82 and 109 m/s. The erodent used is silica sand with the size range 150 – 250  $\mu$ m of irregular shape. The result shows brittle behavior with maximum erosion rate at 90° impingement angle. The morphology of the eroded surfaces was examined by using Scanning Electron Microscopy (SEM).

S. K. Acharya et al (2010) conducted [37] experiments to determine the abrasive wear behavior of bagasse fiber reinforced epoxy composite in different directions, namely parallel orientation (PO), anti-parallel orientation (APO) and normal orientation (NO) by using a two body abrasion wear tester. Three different types of abrasives wear behaviour have been observed in the composite in three orientations and follow the following trends: WNO < WAPO < WPO, where WNO, WAPO and WPO are the wear in normal, anti-parallel and parallel directions of fibres orientation, respectively. The fiber bundles present in the composite provide unique directional abrasive wear properties. Wear anisotropy magnitude of the composite is found to be a function of load and abrasive grit size. The worn surfaces were observed by using a SEM after the wear test. It has been found that in PO type samples the abrasion takes place due micro ploughing, where as in APO and NO type samples micro cutting found to be responsible for the wear process.

John .O. Osarenmwinda et al (2010) investigated [38] the potential of carbonized bagasse (waste from sugar cane) as filler in rubber products. The products were evaluated for Tensile strength, Compression test, Abrasion resistance, Hardness and Elongation at break. Results shows that as the filler loading increased the tensile strength, abrasion resistance, Hardness properties improved. It was also observed that decrease in filler loading enhanced the Elongation at break and compression set properties. The possibilities of utilizing the low cost bagasse as an alternative filler material in natural rubber have been achieved in the work.

Martin et al (2011) used [39] pre-treated sugarcane bagasse with glycerol (40-80% (w/w)) either in the presence of NaOH or H<sub>2</sub>SO<sub>4</sub>, or without any chemicals, at 190 °C, 10% biomass load, for 1 to 4 hours. The pre-treatments resulted in cellulose-enriched fibres and different degrees of xylan and lignin solubilisation. Cellulose recovery was higher in pre-treatments with NaOH addition and without any chemicals, than in those with H<sub>2</sub>SO<sub>4</sub>. Xylan solubilisation was almost complete in all H<sub>2</sub>SO<sub>4</sub>-assisted treatments whereas, in the other experiments, it decreased with the increase in glycerol concentration and increased with the pre-treatment time. Lignin solubilisation increased proportionally with glycerol concentration. Under all conditions applied, the pre-treatment improved the enzymatic hydrolysis of cellulose. The highest overall cellulose convertibilities were achieved in the glycerol pre-treatments without other chemicals (85-94%). Convertibility decreased with time in acidic pre-treatments and increased slightly for the other ones. Enzymatic conversion of the xylan retained in the fibres was also detected.

Rahman Muhammad Bozlor et al (2011) describes [40] a method to fabricate short bagasse /bamboo fiber reinforced biodegradable composites and investigated their flexural properties. Bagasse/bamboo fibers were simply randomly mixed with biodegradable resin and composite specimens were fabricated by a cylindrical steel mould by the press forming. The effects of holding time and fibers content on the flexural properties of bagasse / bamboo fiber composites were investigated. The flexural properties of bagasse / bamboo fiber reinforced biodegradable composites were strongly affected by the holding time and amount of fiber content. During fiber processing on different holding time, it was found that flexural properties increased with the increased the holding time up to 10 min. Above 10 min, flexural properties decreased due to insufficient resin. In processing on fiber content, it was observed that the flexural properties increased with the increase in the fiber content up to 50% & above 50% flexural properties decreased due to high fiber weight fraction and poor bonding between fibre and matrix. The flexural modulus for holding time showed maximum of 2384 MPa for bagasse and 2403 MPa for bamboo composites. The cross sectional structure of bagasse fibre was porous and bamboo fiber was solid.

P. C. Gope et al (2012) developed [41] bagasse-glass fiber reinforced composite material with 15 wt%, 20 wt%, 25 wt% and 30 wt% of bagasse fiber with 5 wt% glass fiber mixed in resin. Scanning electron microscopy (SEM) shows that bagasse fibers 13.0  $\mu$ m in diameter and 61.0  $\mu$ m in length are well dispersed in the resin matrix. Addition of fiber increases the modulus of elasticity of the epoxy. Mixing of bagasse with glass fiber also improves the modulus of elasticity. Addition of bagasse fibers decreases the ultimate tensile strength. But addition of glass fiber further increases the ultimate tensile strength in comparison to commercially available bagasse based composite. Bagasse-glass reinforced fibers improve the impact strength of epoxy materials due to fiber has more elasticity in comparison to matrix material. Addition of fibers increases the capacity of water absorption. This test is necessary where composites are used in moisture affected areas. Addition of bagasse fiber reduces bending strength. But addition of glass fiber further increases the bending strength in comparison to commercially available bagasse based composite.

## 5. Review Objectives

The present review focuses on the progress of bagasse fiber in the development of composites, an effort to utilize the advantages offered by renewable resources for the development of bio composite materials.

The present review focuses on the enhanced properties of bagasse fiber as composites. It is a challenge to the creation of better materials for the improvement of quality of life with better mechanical properties.

The present review also focuses on the use of bagasse fiber as filler in composite material, which is a waste product from sugar factories.

The objective of the present study is to utilize the advantages offered by renewable resources for the development of composite materials based on bagasse fibers.

## Conclusion

The present review has been undertaken, with an objective to explore the potential of the bagasse fiber polymer composites and to study the mechanical properties of composites. The present review reports the use of bagasse fibers, as reinforcements in polymer matrix. This review focussed at providing knowledge to enhance further research in this area. Natural fabric-based thermoset composites are generally lower in strength performance compared to hybrid composites. However, they have the advantages of design flexibility, cost effectiveness, lack of health-hazard problems and recycling possibilities. Hybridization with some amounts of synthetic fibers makes these natural fabric composites more suitable for technical applications such as automotive interior parts. The possibility of surface chemical modification of bagasse fibers have been extensively used in a wide variety of application, e.g., packaging, furnitures and electronic display materials. The present contribution defines some selected works in the field of bagasse fibers. The influence of the source of bagasse fiber on the mechanical properties of bio composites was reported. A natural fibre, when used as reinforcement, gives good result as compared to the technical fibers such as glass fiber. The merits of glass fibers (technical fibers) are good mechanical properties; which vary only small, while their demerit is difficulty in recycling. Several natural fiber composites achieve the mechanical properties of glass fiber composites and they are already applied, e.g., in automobile and furniture industries. At present, the most important natural fibers are Jute, flax, bagasse and coir. The future of bagasse fiber composites appears to be bright because they are cheaper, lighter and environmentally superior to glass fiber or other synthetic fiber composites in general. Future research should hence focus on achieving equivalent or superior technical performance and component life.

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